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Construction Engineering Research Laboratory

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Army Threatened and Endangered Species Research Program

Threatened and Endangered Species Surveillance in Inaccessible Areas

A Feasibility Study

Harold Balbach, Donald Pitts, William Meyer, and Scott Tweddale

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Threatened and Endangered Species Surveillance in Inaccessible Areas

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Final report

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Abstract: Monitoring threatened and endangered species on Army installations is not always feasible with respect to the areas that are either inaccessible or have limited times for entry. When biologists are unable to enter an area freely for periodic surveys, it prevents normal application of standard methods, which results in the data being unavailable for reporting either management successes or problems. If these species are present in the inaccessible area, they cannot be credited toward management goals. The total population of the installation is assumed to be smaller, which can result in unnecessary expense and greater regulatory interference. This research examines each of the four broad categories of platforms (1) remote sensing, (2) airfoil aircraft, (3) lighter-than-air craft, and (4) ground surveillance instrumentation for remote or non-intrusive acquisition of data relevant to these species. The data might be of any nature, including spatial relevance, sound, presence or absence, or other categories. Some technologies, such as satellite and aerial imagery, continue to fill important niches, which are generally well understood. The overall conclusion of this survey was that there are no fully satisfactory, affordable platforms that can provide the full set of data acquisition needs for inaccessible areas.

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Preface

The research documented in this report was performed during the period 2004 through 2006 as part of Work Unit JF83F2, Priority T&E Species Impact & Characterization, “Training Lands Management—Characterization, Analysis, and Mitigation,” under program element P622720, Army Environmental Quality Technology, in support of the Army Threatened and Endangered Species Research Program. The Technical Monitor at the time this work was performed was Bill Woodson. Scott Belfit now fills that role.

This research was conducted under the guidance of Dr. Don Pitts, Principal Investigator, and Dr. Hal Balbach, Principal Investigator, in the Ecological Processes Branch (CN-N), Installations Division (CN), U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC/CERL). We wish to state our appreciation for the special efforts made by Elizabeth Keane, ERDC-CERL, in coordination of the many drafts of this report among the several authors, and the preparation of the final version from these numerous submissions.

At the time of this report’s publication, Tim Hayden was the TES Program Manager, Alan Anderson was Chief, CN-N, and Dr. John T. Bandy was Chief, CN. The associated Technical Director was Dr. William D. Severinghaus, CV-T. The Director of CERL was Dr. Ilker Adiguzel.

COL Richard Jenkins was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
feet	0.3048	meters
inches	0.0254	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
pounds (mass)	0.45359237	kilograms
yards	0.9144	meters

1 Introduction

Background

There is a requirement for surveying and monitoring threatened and endangered species (TES) on Army installations, but this is not always feasible due to their presence in inaccessible areas and in areas with limited entry capability. Impact areas and their safety overfire zones are obvious examples, but restrictions on road use and other safety and security regulations may also exist. Biologists are often unable to enter an area freely for periodic surveys, which prevents application of normal survey methods, in turn resulting in the possibility of uncounted TES in the area. This is problematic in the overall population dynamics of the ecosystem as well as in meeting installation population goals. If TES are, in fact, in an inaccessible area, their numbers are not credited to the goals. The total population of the installation will be assumed to be smaller, which can result in unnecessary expense and greater regulatory interference.

Presence of TES in an inaccessible area such as an impact zone may also not hinder Army training. If a population can thrive in an impact zone, this would indicate the species is compatible with this intensity of training and should serve to speed the NEPA process of establishing other impact zones and other areas of high intensity training.

There are also situations in which legal, non-intrusive surveys for TES on private property would be advantageous to the Army. Knowledge of existing individuals near the installation could have the effect of lowering population goals on the installation as the breeding population would be considered larger and genetic diversity opportunities greater. Private property owners are often hesitant to allow TES surveys since discovery of these species could result in regulatory difficulties.

This requirement to survey and monitor TES has been established and there have been previous attempts to find solutions. In 2001, for example, Fort Benning, GA, attempted to find methods for surveying the red-cockaded woodpecker and gopher tortoise in impact areas, and drafted a proposal in response to a Strategic Environmental Research and Development Program (SERDP) Statement of Need which included this topic (P. Swiderek, personal communication). SERDP did ultimately fund Cornell University to experiment with lighter-than-air platforms for such surveys. The Fact Sheet describing this effort is attached (Appendix A).

Problem

The requirement and conceivable benefits of performing such surveys has caused the Army to search capabilities and case studies of some significance. This report is an effort to consider a very wide range of possibilities for such surveillance using current technology or technology that might be developed in a cost efficient manner.

Approach

As a scoping study, a team of four researchers gathered to compare their personal knowledge and areas of interest. Each researcher then performed reviews within his area of interest. Broadly, these areas of interest were: (1) remote sensing, (2) airfoil aircraft, (3) blimps and other lighter-than-air aircraft, and (4) ground surveillance such as sound sensors and optics. These studies relied almost completely on already-developed analyses and discussions, and many items from the various studies are reproduced here with appropriate source attribution.

As an overview of capabilities, Hansen et al. (1999; Appendix B) present a simple comparison. A myriad of platforms have been tested and used for image capturing under various requirements, and each has its advantages and disadvantages.

Scope

All information incorporated here has been derived from secondary sources, including formal publications, internet postings, and personal conversations with numerous persons involved with the various systems. No personal testing or experimentation was conducted by the authors, and the opinions included are not necessarily based on specific data sources.

Mode of technology transfer

The information included in this report is one portion of the materials prepared by the Engineer Research and Development Center (ERDC) to assist installation natural resources and TES program managers. It is believed that this overview will assist these managers, and contractors employed by them, who will be performing TES and other surveys, to develop a better understanding of the present and future potential for unmanned aerial platforms to assist in such surveys. The emphasis here is on survey of inaccessible areas, although this is not an absolute statement of potential applicability of such techniques, especially as systems evolve in the future in this rapidly-changing field. This report will be made accessible through the World Wide Web (WWW) at URL: http://www.cecer.army.mil.

2 Approach

The approach here is to examine through study of the literature and corporate and agency websites each of the four broad categories of platforms for remote or non-intrusive acquisition of data relevant to threatened and endangered species. The data might be of any nature, including spatially relevant, sound, presence or absence, or any of numerous other categories. It is recognized that some platforms or methods are applicable to all types of data, while others may support only limited types. No attempt was made to match requirements across platform boundaries, so the evaluations are non-parallel in that sense.

A distinction also needs to be made here among the different types of observation that might be needed or anticipated. The vast majority of the aerial platforms discussed here, in all classes, are more applicable to observation than to mapping applications. While the application of remote sensing has been common for broad area coverages, which are then capable of being assembled into layers or mapped coverages, the typical pilotless platform cannot perform the rigorous banded flight lines necessary to accomplish this. They can, however, observe individual locations, and acquire images to enumerate waterfowl at rest, for example, on a particular lake. Actually mapping the total land or water area systematically is beyond current system capabilities in all but the most advanced platforms.

Remote sensing

Traditional ground-based and labor-intensive field inventory and monitoring protocols for characterizing and monitoring TES habitats across Department of Defense (DOD) installations are cost-prohibitive, particularly if repeated surveys are required for monitoring purposes. Remotely sensed imagery, because of its large geographic coverage and high temporal frequency, provides an ideal supplement, or surrogate, to costly field surveys. In addition, because imagery provides a complete census of the landscape, it is possible to assess areas that are otherwise inaccessible to field surveys (e.g., impact areas or adjoining private land).

Remote sensing is a technology of increasing importance in wildlife habitat studies, and when remotely sensed data is combined with other spatially explicit data using geospatial technologies, it has the potential to greatly enhance the speed, accuracy, and economy of TES habitat assessments. Remote sensing provides a valuable tool for characterizing key physical and biological parameters of habitats. However, data extracted from remotely sensed imagery alone is generally insufficient for delineating preferred or potential habitat for a species, as there are typically additional habitat parameters that cannot be observed from remote imagery. Instead, data extracted from remotely sensed imagery is typically combined with ancillary data and used as input to predictive habitat suitability models.

Numerous modeling techniques have been applied for the purpose of assessing habitat suitability. In addition, there are a large number of landscape indices that have been developed to quantify spatial patterns of the landscape that are critical to evaluating suitability of habitat (Corsi et al. 2000, de Leew et al. 2002, Guisan and Zimmermann 2000, Skidmore 2002, Woodcock et al. 2002).

The DOD and many other federal, state, and private land owners have investigated and implemented a wide variety of TES inventory and monitoring programs that utilize a combination of field surveys and remotely sensed imagery. Although advances have been made with respect to certain TES and their preferred habitats, significant information gaps still exist. Many TES monitoring protocols are still inefficient and lack the accuracy required by regulators. As a result, standard protocols to inventory and monitor TES habitats across large geographic areas are lacking. The information gaps are sometimes due to a lack of understanding of basic habitat requirements for some species.

In other cases, the basic habitat requirements of a species are well understood, but information gaps exist because field monitoring protocols are cost-prohibitive and because of the inability of remote sensing technologies to discriminate critical parameters that define viable habitat. Significant resources have been expended to develop inventory and monitoring programs that incorporate remote sensing protocols and geospatial technologies by federal, state, and private land owners. As a result, a vast amount of literature exists on these topics. Most of the literature spans a period from the late 1970's to the present, which corresponds to the time period that commercially available satellite imagery has been available to the research community. During this time period, most of the literature focused on the use of passive spectral systems (e.g., Landsat Multispectral

Scanner [MSS] and Thematic Mapper [TM] and SPOT imagery) with relatively limited spatial resolution (20 to 80 meters) for monitoring TES habitat. With the emergence of high spatial and spectral resolution and active and passive sensors, the literature suggests that these systems may be able to address critical information gaps in TES habitat monitoring, such as sensing of sub-canopy components of forests and woodlands or improved ability to determine species composition.

To address these information gaps, the U.S. Army Corps of Engineers' Engineer Research and Development Center's Construction Engineering Research Laboratory (ERDC-CERL) has initiated a research project titled "Remote Sensing for Threatened and Endangered Species (TES) Habitats". The objective of the project is to develop and refine cost-effective and accurate protocols and techniques to identify and monitor viable habitat for TES from a combination of field surveys and remotely sensed imagery, allowing for interpretations of large and inaccessible areas. The goal is to investigate the utility of rapidly advancing remote sensing technology that may help overcome limitations of traditional sensors, and develop inventory and monitoring protocols that not only address habitat characterization and monitoring requirements for the seven DOD, high-priority species, but also are adaptable to other species as they become critical to management of DOD lands. The report by Tweddale and Melton (2005) provides a general overview of relevant literature describing the best available science and protocols currently implemented to characterize and monitor habitat for TES, with a particular emphasis on the seven high-priority species.

However, this project is focused on the application of geospatial technologies for characterizing and monitoring the habitats of fauna, with an emphasis on the habitats of species that are high priority to DOD. In some cases, a specific habitat characteristic may be common to multiple species, and therefore, the methods to define that individual characteristic may be applicable and adaptable to other species. This project does not address remote sensing techniques for detecting the presence or directly monitoring the movements and behavior of fauna, nor does it specifically address remote sensing techniques for characterizing threatened and endangered flora. In most cases, aerial photography and satellite imagery does not provide adequate spatial resolution to determine the presence or number of individual TES.

Remotely sensed imagery acquired from unmanned aerial vehicles (UAVs) allows for image capture close to the ground surface, and thereby provides superior spatial resolution, which may be necessary to detect individual TES. In addition, UAVs can be mobilized rapidly and often to meet monitoring requirements, while collection of remotely sensed imagery from airplanes and sensors requires considerable mobilization time and expense. Acquisition dates and times for satellite imagery are predetermined according to the orbit characteristics of the sensor. Some UAVs such as blimps, for example, also provide the capability to remain stationary for extended periods of time over the same area on the ground, thereby allowing for surveys over a longer period of time.

At the highest level, the Navy has the Broad Area Maritime Surveillance (BAMS) system (Figure 1), which is unlikely to be of benefit for TES monitoring, though it could prove useful in identifying habitat on the landscape scale. Noted for high speed and long endurance, this vehicle is also capable of extremely high altitudes.

Figure 1. The Broad Area Maritime Surveillance (BAMS) concept was developed by the U.S. Navy to address an identified shortfall in assets for conducting intelligence, surveillance, and reconnaissance (ISR).
The BAMS program is designed to off-load a significant portion of the ISR mission, currently maintained by its P-3 fleet today, using UAVs, to augment and complement this critical capability as they transition to their new multi-mission maritime aircraft.

At present, there is no remote sensing technique on the horizon that appears feasible in TES monitoring or surveying. As photo imagery technology improves, it is conceivable that there will be future uses of these techniques in wildlife surveys.

Airfoil aircraft

This category includes helicopters and fixed wing aircraft, and could include, by definition, the BAMS system. Although there is great versatility, whether manned or unmanned and operated by remote control, there are also inherent problems in using these craft for TES surveying. Their primary problem is noise, and any of these vehicles will produce a noise level that will likely be disruptive to the wildlife and to audio sensory devices. The motor of a fixed wing aircraft will likely preempt audio surveys. Since fixed wing aircraft have minimum speed requirements to stay aloft, wind noise is another impediment. Testing would also be required to determine if the noise and presence of the aircraft caused birds to cease singing as they would were an avian predator to pass overhead.

Airfoil aircraft do have potential as a photo imagery platform for certain species such as the gopher tortoise, where most survey methods are counting burrow holes and aprons rather than individuals. The military is presently using unmanned aerial vehicles in warfare situations for surveillance of large areas and for actual ordnance delivery and these vehicles could be ideal for surveying large species in open areas, such as pronghorn antelope in an impact area or bombing range. Their higher cost, larger size, and faster speeds presently will usually make them impractical for most TES surveys.

Most TES surveys (observations) can be conducted from a much smaller, less expensive platform, and both helicopter and fixed wing models are available. Plice et al. (2002) explored varieties available for surveys on Mars.

Small, unmanned aircraft operated by remote control do have the advantage of rather precise control. They can be flown in a straight line as in a transect survey, or operated in such a way as to cover entire quadrats or even 100 percent of the study area. The helicopter designs may be used to precisely observe an area of interest. A disadvantage is that for use in other than a straight line transect, visual contact is required and this may not be possible in many circumstances.

UAVs of one type or another have seen a flurry of development for both Defense and civilian applications since the 1970s. At least a score of manufacturers, in the United States and abroad, have developed numerous prototype and production vehicles. This discussion is limited to fixed-wing vehicles; a further limit is to those that have, or could, carry some type of information-gathering sensors. Further, this discussion addresses only those platforms that are considered reasonably available for use in the non-combat role of acquisition of natural resources and related information. This limitation means that cost is a significant factor, as is the level of training and skill required to operate the vehicle safely.

The NASA Wallops Island Flight Facility has prepared a table showing the characteristics of those UAVs they consider to be "available" (Table 1) meaning that they are in production and, theoretically, may be purchased or contracted to perform information acquisition missions (http://uav.wff.nasa.gov/).

Table 1. Basic characteristics of UAVs considered available by the NASA review.

Unmanned Aerial Vehicle	Endurance (Hours)	Payload (Pounds)	Altitude Feet	Altitude Feet	Cost
Aerosonde*	40 hrs.	2.2 lbs.	20,000 ft.	1800	$40K
Altus2	24 hrs.	330 lbs.	65,000 ft.		N/A
AQM-34**	1.9 hrs.	470 lbs.	60,000 ft.		N/A
Exdrone	2.5 hr.	25 lbs	10,000 ft.	565	N/A
Global Hawk	42 hrs.	1,960 lbs.	65,000 ft.	14,000	$10M
Gnat 750*	48 hrs.	140 lbs.	25,000 ft.	3000	$1.8M
Pioneer	5.5 hrs.	75 lbs.	12,000 ft.	115	$900K
Shadow 200	4 hrs.	50 lbs.	15,000 ft.	32	N/A

* Considered by NASA to be "available" as of 2004.
** The AQM and closely related BQM share most specifications. We have updated the original table with current information for the BQM where available

Of these, only two are considered in production and available for evaluation. The Aerosonde (Aerosonde Robotic Aircraft Ltd.; http://www.aerosonde.com) has a stated cost of approximately $40,000, including the ground support station. The Gnat 750 (General Atomics, http://www.ga.com/asi/aero.html), in contrast, has a stated cost of approximately $1.8 million for the aircraft, plus an additional $5 million for the ground control station equipment. Thus, the former might be considered for this program, while the latter likely could not be justified.

More to the point of the potential for the Army TES research program to identify vehicles that might be applicable to installation natural resources applications, the NASA Wallops Island UAV research program examined, in significant depth, potential low-cost platforms for remote sensing. Their findings are presented on their website at http://www.aeroconcepts.com/UAVHome.html.

Of the instrument packages that were evaluated, all common sensor systems, including streaming video, magnetometer, and thermal scan, the most relevant to current Army needs appears to be the Variable Interference Filter Imaging Spectrometer (VIFIS) package. The VIFIS Instrument, developed in the 2000–2001 time frame, comprises: (3) Sony XC - 8500 CE 1/2-in. CCD progressive scan cameras, a half desktop sized Pentium 200 MHz MMX computer; 64 MB memory; 9.1 GB UltraWide SCSI disk; 100 Mbit/sec Ethernet card; 3 channel digitizer; Integrated (differential capable) GPS receiver; and Windows NT operating system. Effectively, this was a hyperspectral camera with a very wide range of operational capabilities.

In NASA's evaluation and testing, the vehicle that carried this package was the TERN (BAI Industries; http://www.baiaerosystems.com) (Figure 2). The specifications for the TERN are:

Length: 8 ft (2.4 m)
Wingspan: 11 ft (3.3 m)
Payload Weight: 25 lb (11 kg)
Max Gross Weight: 120 lb (54.4 kg)
Cruise Speed: 55-60 kt (102-111 km/hr)
Max Speed: 101 kt (187 km/hr)
Propulsion: 9.5 hp Gasoline
Endurance: 2-4 hr

Figure 2. The TERN.

The NASA website also provides an example image acquired by the TERN in a test flight at the Wallops Island Flight Facility (Figure 3). Although this particular oblique image does not illustrate a mapping style photograph, it does illustrate that the VIFIS package is capable of acquiring and transmitting images to the ground station. The operation of such a system is portrayed diagrammatically in Figure 4 4 and 5.

Figure 3. Wallops Island Test Facility. Image acquired by TERN.

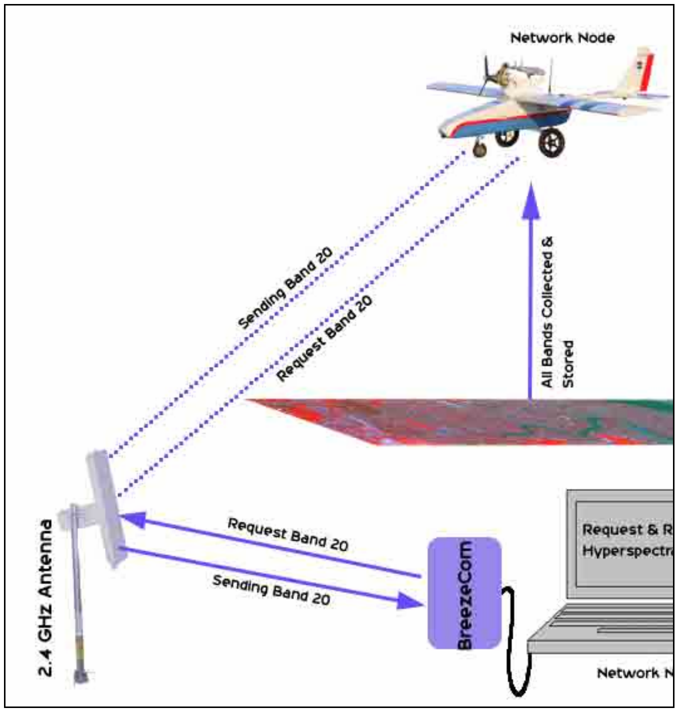

Figure 4. Operation of the VIFIS package as installed in TERN.

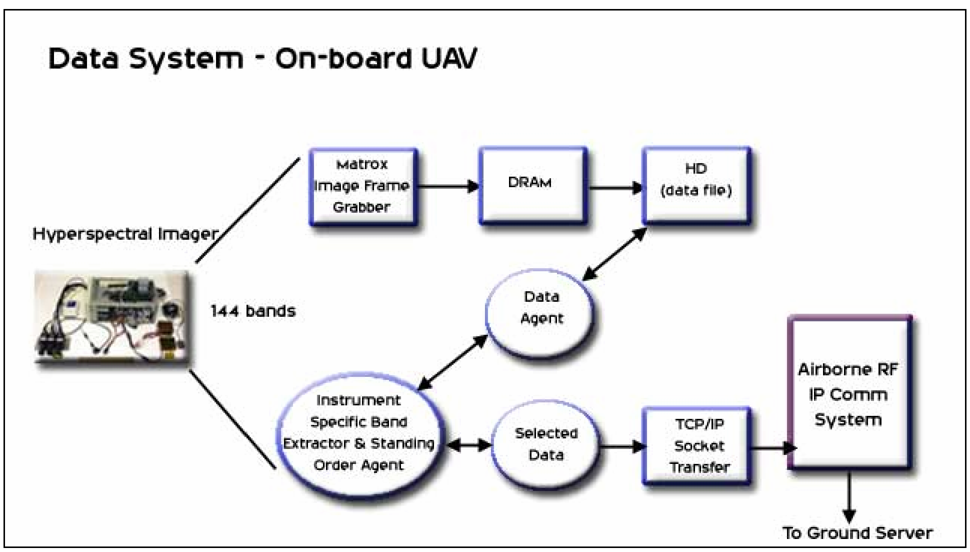

Figure 5. VIFIS data acquisition and transfer schematic.

This effort by NASA essentially duplicated anything that would be likely to be developed within the TES program, at least as now envisioned. Therefore, it is strongly recommended that we pursue partnering with the team that performed this work, and which still has a small, but functional, research program. In discussions with the Principal Investigator for the small UAV project (Patrick Coronado, of the NASA Goddard Space Flight

Center) and the Flight Team Leader (Geoffrey Bland, NASA GSFC/Wallops Flight Facility) in March 2005, Mr. Coronado and Mr. Bland were not only interested, but enthusiastic with a potential cooperative effort. Mr. Coronado stated that the Earth Sciences program within NASA would be likely to assist in funding any efforts by the Wallops Island group. It was also proposed that Mr. Bland visit ERDC-CERL to further discuss what they might be able to contribute to any cooperative effort. A summary of the NASA platform and sensor evaluation is attached (Appendix C), as are fact sheets for some of the known UAV platforms (Appendix D).

Surveillance optical equipment will primarily be live, with images constantly received during the flight, recorded for later review and analysis. There may be situations in which a series of still images will be used, captured in sequence during the course of the flight. With present technology, when camera weight is a deciding factor, the still images can be captured by smaller, lighter equipment.

The use of airfoil aircraft for TES surveys is a distinct possibility with the existing technology and should be tested in a situation in which ground truthing is also possible. The aircraft and the optical equipment are available, though some testing and further study is necessary to determine the right combinations for each type of survey desired. It is likely this system will prove useful for certain types of surveys and species and not for others.

Lighter-than-air platforms

TES surveillance using lighter-than-air platforms has already been tested by the Army with some success, and some platforms are in use in Iraq (Figure 6). Figure 7 shows a blimp with numerous military applications, including border surveillance.

Figure 6. An aerostat blimp used in Iraq.

Figure 7. Blimp used for photographic surveillance with the ability to carry a human crew.

Balloons, blimps, and other lighter-than-air platforms come in a wide variety of sizes: from the size of a basketball to the extremely large craft designed to carry a crew of humans. Typical size for unmanned surveillance is 35 to 40 feet (10.7 to 12.2 meters), and these can carry surveillance equipment up to 100 pounds (45.4 kilograms). The size of the platform is directly proportional to the load it can carry.

These platforms have the advantage of silence, though motorized versions will have some engine noise. This is mitigated by distance from the engine since these craft are much larger than airfoil platforms, and the engine is less powerful because it does not have to keep the platform aloft as is again the case with airfoil platforms. These craft will move at a much slower rate and can remain stationary if necessary, reducing wind noise and making them more versatile than fixed wing aircraft.

Essentially, as balloons, their light weight and large size result in their ability to be easily manipulated by winds. Unless tethered, these craft are not usable in high winds, and, in fact, require extremely light winds. Control by remote apparatus, not tethered, is difficult to impossible in higher winds. However, this wind limitation is not unique. Airfoil aircraft also have some, though lesser, wind limitations, and even terrestrial surveys have wind limitations resulting in the inability to hear bird calls. Instructions for point counts, as agreed upon by ornithologists, suspend point count surveys when winds exceed 20 miles per hour (32.2 kilometers per hour). An interesting example of the application of a free-floating balloon was the SERDP project SI-1185, see Appendix A. The project used a balloon with audio detection equipment floating over bird nesting areas, recording the number of singing males establishing territories. Validation is still incomplete, and among the issues requiring study is the reaction of many species to the presence of the balloon.

Figure 8 is similar to a typical remote controlled blimp that can carry audio and optical equipment, and can return data from a distance of 4 miles (6.4 km). Figure 9 describes a platform large enough to carry a small human crew.

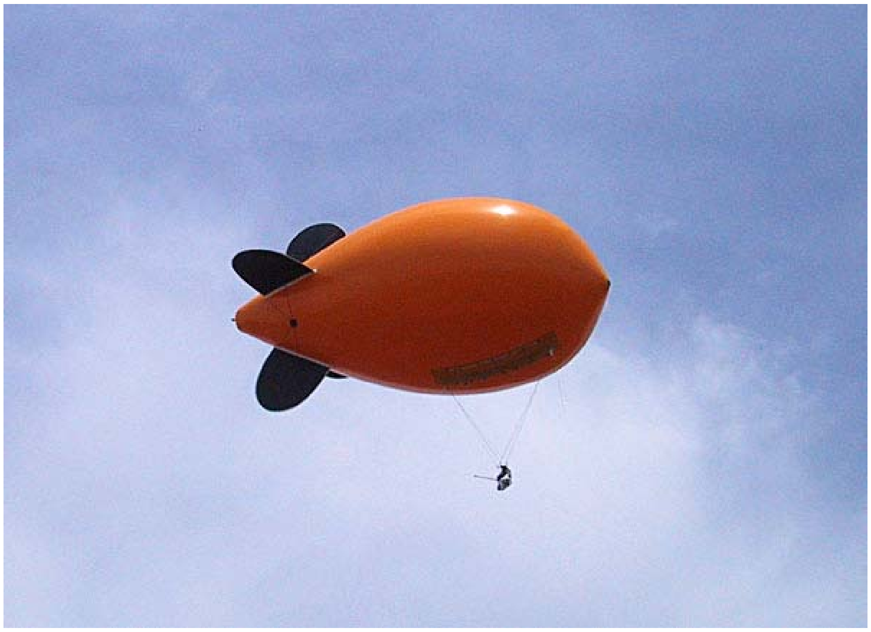

Figure 8. Remote controlled blimp supporting a camera and microphone.

Figure 9. Blimp with the capability to fly human crews.

These platforms still must be tested for species-specific response to having a large craft over the habitat. Some birds may flush, some may stop singing, and some may ignore it. These platforms are very adaptable to terrestrial surveys such as the gopher tortoise or kit fox burrows, and are very adaptable and proven successful for marine animal surveys (see Figure 10). Platform and survey equipment will vary for each type of survey and the targeted species, and requires testing in a situation in which ground truthing is possible.

Figure 10. Blimp and equipment used for wildlife monitoring.

Ground surveillance

In the case of smaller inaccessible areas, surveys may be conducted from the perimeter. Figure 11 describes an inexpensive, hand-held listening device that can pick up bird calls from distances of 300 ft (91.4 m); this distance could well be doubled depending on the species. Birding scopes extend visual capabilities to distances greater than 500 yd (457 m) for some larger species. A combination of enhanced audio and visual devices could produce defensible results without entering a smaller area.

Figure 11. Orbitor Electronic Listening Device with the ability to amplify bird calls from 91.4 meters away.

Audio equipment is the most likely solution for most remote surveys, and can be particularly useful if the inaccessible area can be entered for initial installation of the equipment. This is very likely possible. Although biologists and range management would agree that frequent entry into an impact area is unwise and unsafe, a once per annum entry accompanied by trained ordnance personnel is not an unreasonable request. This is done quite often on military installations, where the biologists are accompanied by explosive ordnance disposal (EOD) personnel. Current accelerated training schedules may, however, make even infrequent access impractical.

For male breeding call surveys, a grid of microphones can be placed across the area. In one example the methods dictated that the microphones are to be spaced 54.7 yd (50 m) apart, and each microphone can pick up the call of a bird from several hundred meters. This is relatively inexpensive, and since the locations of the microphones are known, programs are developed that can note the time a call reached each microphone, and in this manner pinpoint the location of the bird. Since signing males are territorial, numbers and densities can be derived for the entire area. A sampling percentage of the inaccessible area is all that is required, though a 100 percent census is possible.

Hobson et al. (2002) reported acceptable accuracy using omnidirectional microphones capable of recording birds' calls at distances of 164 yd (150 meters). Peterson and Dorcas (1999) reported omnidirectional microphone surveys to be superior to point count surveys, both in capturing more species and individuals, and also missing fewer known to be present in validation tests. They also reported similar results in frog and toad surveys.

Audio surveys are common and have been used over very large areas. Evans and Rosenburg (1999), in their report on acoustic monitoring on night-migrating birds, describe a 31 mi (50 km) long network of microphones used to record bird migration patterns. Since most passerines migrate at night and their exact route is not certain, this use of audio technology may be used to record species and numbers of those species and their migration routes.

A survey using microphones in an impact area would be designed along the lines of a once-per-year entry, timed prior to the arrival of the males of the species to be surveyed. Technicians enter the impact area accompanied by EOD personnel and set out the microphones in the pre-designed grid. Monitoring takes place using the receivers during the season of establishing and defending territories. Male singing may be enhanced by playing recorded or computer generated songs of males of the species.

Maintenance of the microphone grid is performed once per year in the same manner in which it was installed. Although this method has already been proven, in the case of impact and other training areas, the viability and survivability of the audio equipment is questionable and will require testing under actual conditions. If acceptable survivability is achieved, the primary obstacle will be the timely accessibility required to perform the survey. This method is likely the least expensive of those reviewed during this research, but is limited to audio surveys.

3 Conclusion and Recommendations

Significant technology exists to facilitate TES inventory in inaccessible areas. The types of methods used will depend on several factors such as the species being questioned, size of the study area, and requirements for visual or audio observation. Many of these technologies have been tested already in plant and wildlife monitoring with at least some success. In a few cases, such as the audio survey from a grid of microphones, the methods have been proven successful. Lighter-than-air platforms have also been anecdotally shown to be successful, though the full results of the largest study (by Cornell University, Appendix A) have not yet been published.

A distinction may need to be made between the use of these platforms for *observation* versus their potential application in *mapping*. For the former need, they may be considered well-proven to be useful. For the latter, however, the need to generate exact, parallel flight lines that cover a sizable land area—a typical Army installation may be 100,000+ acres—at an acceptable level of detail requires precise navigation which appears not to be common in lower-cost systems, such as many we reviewed here. Applications that may be satisfied by acquisition of a single scene may, however, be adequately georeferenced or simply viewed to obtain the information desired.

The capability to perform many surveys presently needed by the Army but not yet attempted is most likely available, but will require what is essentially fine-tuning, testing, and validation. It is these final steps that ERDC/CERL and the Army should pursue in order to finally complete these surveys in an acceptable manner. If the audio grid system is not feasible because of a species or a situation, then the most likely solution will be lighter-than-air platforms, with some possibility for success using fixed-winged aircraft in certain situations. Increased levels of sensitivity to the security issues related to overflights by these or any aircraft are, however, making the task more difficult to implement in practice.

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Appendix A: Fact Sheet

SERDP Strategic Environmental Research and Development Program

Acoustic Monitoring of Threatened and Endangered Species in Inaccessible Areas

Conservation
CS-1185

Background:

Many U.S. military installations find it difficult or impossible to monitor the status of federally listed threatened and endangered species on large portions of land because these areas are inaccessible to ground personnel. Military activities, such as live-fire exercises, and safety hazards, such as unexploded ordnance, restrict or prohibit direct ground access to these areas. Biologists, therefore, are unable to use traditional ground-based survey methods in these areas. However, the Department of Defense (DoD) is required by the Endangered Species Act to collect such data and to use this information to develop management plans for minimizing the impacts of military activities on threatened and endangered species.

Objective:

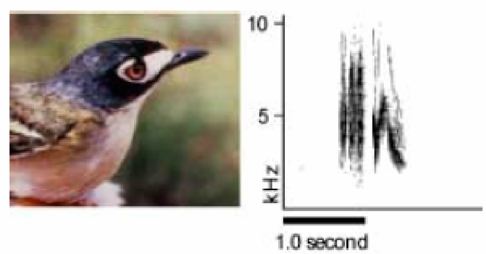
This project will develop an autonomous airborne monitoring system for censussing acoustically active animal species in inaccessible areas by recording, identifying, and localizing their sounds. The system will be developed and initially deployed for use in monitoring populations of two federally endangered songbirds (golden-cheeked warbler and black-capped vireo) at Fort Hood, Texas. The ability to extend this technology to other bases and species will also be demonstrated.

Summary of Process/Technology:

The monitoring system will consist of the following three components: (1) a microprocessor-controlled digital data recording system that can be deployed either on the ground or on an airborne platform; (2) a helium-filled lift vehicle that can carry the recording system aloft for drifting or tethered deployments; and (3) a software package for automatic extraction, identification, and localization of sounds of interest. The completed system will enable long-term or wide-area acoustic monitoring, with fully automatic data reduction. Post-deployment processing will be capable of producing a map of sound source locations and a log of species and time of call for all detections of interest. Summary statistics regarding call density, the estimated density of animals, and measures of the uncertainty of these estimates will be produced.

Benefit:

The data collected by this system can be used to determine the presence or absence and the estimated population density of target species in areas where such data are presently unavailable. These data can be used by DoD resource managers to support the development of effective management plans for threatened and endangered species on many U.S. military installations.



A black-capped vireo (left), one of the endangered songbird species to be monitored in this project. Sound spectrogram of a song of a black-capped vireo (right).

Accomplishments:

This is a FY01 New Start project.

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Appendix B: Comparison of Platforms for Capturing Aerial Images

From Hansen et al. 1999.

Table 3-1. Comparison of platforms for capturing aerial images.

Platform	Height Range (meters)	Resolution Quality	Representative Pixel Size	Advantages	Disadvantages	Best Application
Tripods & Handheld Poles	1-7	Very High	1 cm	Inexpensive and can be operated by one person	Field of view is relatively small with limits on height of the tripod or pole due to unstable wobbling	Small plots of very high resolution and shrub silhouettes or foliar density
Kites	20-150	Medium	1 dm - 1 m	Relatively inexpensive	Equipment not readily available commercially, camera weight is a problem, requires a slow steady wind--does not work without wind or in high winds; limited to below 500 feet; hard to position.	Medium-to-high resolution landscape images that do not have to be aligned with ground plots
Tethered Balloons & Blimps	10-150	Medium	1 dm - 1 m	More steady platform for pictures than balloons	Equipment not readily available commercially, requires calm conditions; limited to below 500 feet; requires two people and a closed trailer to move from site to site.	Medium-to-high resolution landscape images that do not have to be aligned with ground plots
Ultralite	100-300	Medium	1 dm - 1 m	Greater height and maneuverability than kites or balloons.	Requires more expensive equipment; may be hard to maneuver on small sites; motion blurring common; limited in height and acceptable weather, pilot training required, and carries greater risk in flying.	Medium resolution landscape shots that do not have to be aligned with plot dimensions
Helicopter	50-500	High	3 cm - 25 cm	Greatest maneuverability-can hover over site; can be guided by GPS to individual sites	Difficult to shoot in nadir position; vibrations may create auto-focus problems; wind from rotor creates dust and motion problems; is costly to operate; requires two people to operate.	Small areas that do not require much mosaicing of individual images or georeferencing
Fixed-wing Aircraft (amateur)	500-2,000	High	5 cm - 1 m	Relatively easy to maneuver, greater freedom in choosing sites	May be expensive to maintain and may be limited in altitude and rough terrain; usually requires two people to operate; vignetting common; georeferencing required.	Small linear areas at medium resolution that do not require much mosaicing of individual images or georeferencing
Fixed-wing Aircraft (professional)	500-12,000	Very High	2 cm - 3 m	Greater quality of imagery when professional equipment is used; can operate at greater heights	More costly, reduced control over logistics--must be well planned; vignetting common; georeferencing required.	Large areas at medium-to-high resolutions that may require mosaicing, color correction, and georeferencing
Satellite	644-805 (km)	Low	1 m - 30 m	Greater availability of data as there are no flight restrictions or range time required; better georeferencing	Lowest resolution, most expensive for coverage of large areas at high resolutions that are georeferenced	Large areas at low resolutions that may require mosaicing, color correction, and georeferencing

Appendix C: Overview of Status of UAV Applications as stated by NASA

http://uav.wff.nasa.gov

Overview

A number of Unmanned Aerial Vehicles (UAVs) presently exist, both domestically and internationally. Their payload weight carrying capability, their accommodations (volume, environment), their mission profile (altitude, range, duration) and their command, control and data acquisition capabilities vary significantly. Routine civil access to these various UAV assets is in an embryonic state and is only just now emerging.

A buildup of domestic UAV configurations, promoted by the Department of Defense (DOD) occurred in the late 1980s and well into the 90s. This occurred as the DOD sought UAVs to satisfy their mission unique surveillance requirements in either a **Close** Range, **Short** Range or **Endurance** category of vehicle. **Close** Range was defined to be within 50 kilometers, **Short** Range was defined as within 200 kilometers and **Endurance** as anything beyond. With the advent of newer technology and with the demonstrated performance of the UAVs provided to the DOD by industry, the Close and Short Range categories have since been combined, and a later separate Shipboard category has also been incorporated with them. The current classes or combination of these type vehicles are called the **Tactical** UAV, followed by the **Endurance** category.

For the potential civilian user of Unmanned Aerial Vehicles, rather than continue with this terminology for the various categories of UAV, the following category titles are used: **LOCAL**, **REGIONAL**, and **ENDURANCE**.

Within these three categories of vehicles (**LOCAL**, **REGIONAL**, and **ENDURANCE**), approximately twenty-two companies domestically within the U.S. are or have been involved, and represent approximately forty-five different UAV configurations. See the UAV Categories Chart. Individual charts for the available UAVs contained within the Available UAV Characteristics Database are provided. Individual charts for the unavailable UAVs contained within the Unavailable UAV Characteristics Database are provided. (A number of foreign manufacturers also exist, but the information provided herein did not directly focus on these sources.) The appearance of these UAVs and their known performance capabilities and payload accommodations are presented. They range in size from hand-held to runway-operated behemoths, whose payload weight capabilities range from a few pounds to 2000 pounds. Payload accommodation information is presented where available. A comparison of various Unmanned Aerial Vehicle Endurance, Payload Weight, and Altitude Capabilities (see Table 1 in the main document, page 9) is illustrated. Some cost information is also presented. It is pointed out, however, that these data are for information purposes only. Potential UAV users are encouraged to pursue in-depth discussions and analyses with the UAV provider community. It is extremely desirable for UAV providers to make their payload accommodation and cost information more readily available, such that potential users can more easily make tradeoff decisions. To the extent this Web Page can be useful to facilitate that process, an e-mail address is provided. Pertinent information will be posted. Microsoft Word files, JPEG images, etc. are welcome. The e-mail address to send this information to is: Anthony.Guillory@nasa.gov.

Information that a potential UAV science user needs to consider is shown in the UAV Science Mission/Instrument User Questionnaire. Your responses to this questionnaire are encouraged and solicited.

A recent operation was conducted at the NASA Wallops Flight Facility to define the Shock and Vibration characteristics of an Exdrone UAV Payload Bay. The results of this test are presented in the WFF Exdrone Test Report, available in Adobe Acrobat (PDF) format. Similar testing for other UAV types is encouraged, and the UAV provider community is welcome to consider Wallops as a location to conduct such testing, as well as for other operational scenarios. Wallops Control Zone and Restricted Airspace and its ready access to adjacent Warning Areas are viewed as the Key Hole to the sky, thus providing immediate user-friendly airspace access. The Wallops Controlled Airspace and Runway Configuration are shown. Operations within these areas will be assessed by the Wallops Range Safety Office to ascertain risk. Coordination with the appropriate agencies relative to flight operations within these areas will be accomplished. Operations outside these areas will also require risk assessment, as well as in-depth discussions with the Federal Aviation Agency. Aerial photographs of the Wallops Flight Facility and Wallops Island are also shown.

Appendix D: Characteristics of "Available" Unmanned Aerial Vehicles

This information was derived from the NASA Wallops Island Flight Facility website (http://uav.wff.nasa.gov/) on 31 March 2005, and supplemented by information obtained from other sources, including the manufacturer, in 2006 and 2007.

Aerosonde

PHYSICAL CHARACTERISTICS	
Height	n/a
Weight	30.9 lbs.
Length	5.4 ft.
Diameter	n/a
Wingspan	9.5 ft.

PERFORMANCE CHARACTERISTICS	
Altitude	20,000 ft.
Range	approx 1800 nm.
Endurance	40 hrs.
Cruise Speed	70 mph
Maximum Speed	85 mph
Propulsion	gasoline engine

PAYLOAD SPECIFICATION	
Electrical	10 wts.
Weight	2.2 lbs.
Height	max 7 in.
Width	max 7 in.
Length	max 17 in.
Temperature	ambient/payload

COST INFORMATION	
Vehicle	approx $40k including ground station
Ground Station	see above

FOR MORE INFORMATION	
Manufacturer	Aerosonde Robotic Aircraft Ltd.
Website	http://www.aerosonde.com

Altus2

PHYSICAL CHARACTERISTICS	
Height	9.8 feet
Weight	2,150 pounds
Length	23.6 feet
Diameter	n/a
Wingspan	55.3 feet

PERFORMANCE CHARACTERISTICS	
Altitude	65,000 ft.
Range	n/a
Endurance	24 hrs.
Cruise Speed	70 knots
Maximum Speed	80 knots
Propulsion	Rotax 914-2T Dual Turbo

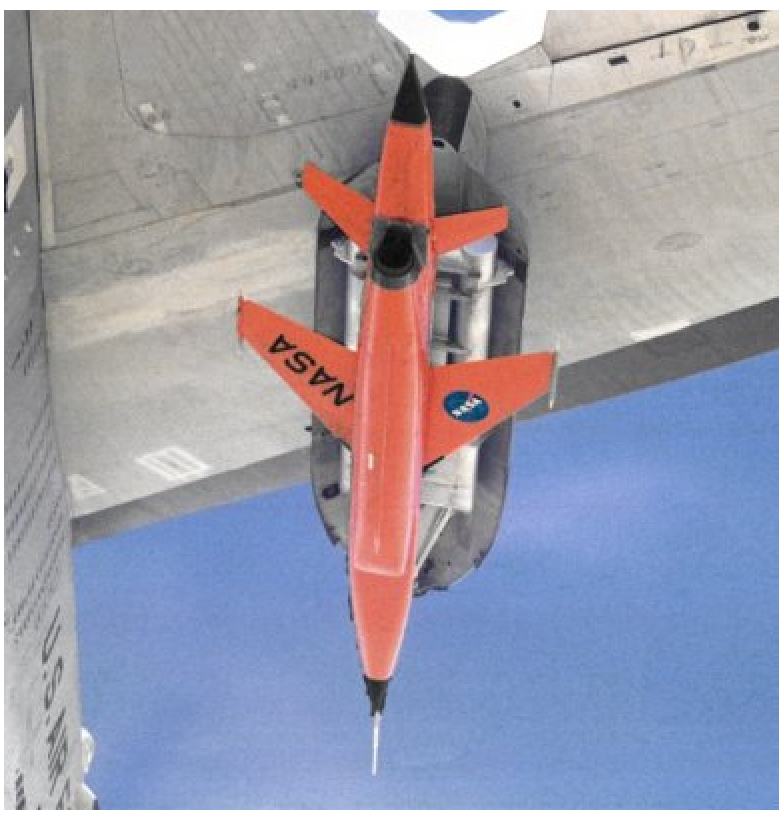
PAYLOAD SPECIFICATION	
Electrical	n/a
Weight	330 lbs.
Height	26 inches
Width	27 inches
Length	58 inches
Temperature	n/a

COST INFORMATION	
Vehicle	n/a
Ground Station	n/a

FOR MORE INFORMATION	
Manufacturer	General Atomics
Website	http://www.ga.com/asi/aero.html

AQM/BQM-34 Firebee

BQM-34F



PHYSICAL CHARACTERISTICS	
Height	6.7 ft
Weight	3,100 lbs
Length	22.9 ft
Diameter	N/A
Wingspan	12.9 ft

PERFORMANCE CHARACTERISTICS	
Altitude	60,000 ft.
Range	n/a
Endurance	115 min.
Cruise Speed	n/a
Maximum Speed	Mach 0.97
Propulsion	n/a

PAYLOAD SPECIFICATION	
Electrical	n/a
Weight	470 lbs.
Height	n/a
Width	n/a
Length	n/a
Temperature	n/a

COST INFORMATION	
Vehicle	n/a
Ground Station	n/a

FOR MORE INFORMATION	
Manufacturer	Northrop Grumman
Website	n/a

Exdrone

PHYSICAL CHARACTERISTICS	
Height	1.6 ft.
Weight	89 lbs.
Length	5.3 ft.
Diameter	n/a
Wingspan	8.2 ft.

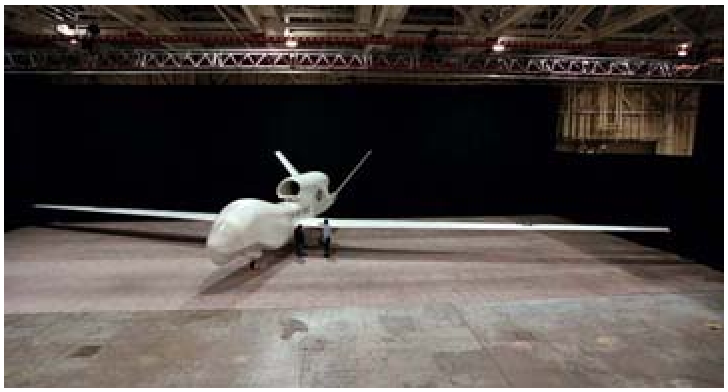
PERFORMANCE CHARACTERISTICS	
Altitude	10,000 ft.
Range	565 mi.
Endurance	2.5 hr.
Cruise Speed	n/a
Maximum Speed	115 mph
Propulsion	8.5 hp gas engine

PAYLOAD SPECIFICATION	
Electrical	n/a
Weight	25 lbs
Height	n/a
Width	n/a
Length	n/a
Temperature	n/a

COST INFORMATION	
Vehicle	n/a
Ground Station	n/a

FOR MORE INFORMATION	
Manufacturer	BAI Aerosystems, Inc.
Website	n/a

Global Hawk



PHYSICAL CHARACTERISTICS	
Height	n/a
Weight	25,600 lbs.
Length	44.4 ft.
Diameter	n/a
Wingspan	116.2 ft.

PERFORMANCE CHARACTERISTICS	
Altitude	65,000 ft.
Range	14,000 nm
Endurance	42 hrs.
Cruise Speed	345 kts.
Maximum Speed	>345 kts.
Propulsion	7,050 st

PAYLOAD SPECIFICATION	
Electrical	n/a
Weight	1,960 lbs.
Height	n/a
Width	n/a
Length	n/a
Temperature	n/a

COST INFORMATION	
Vehicle	$10M exclusive of Ground Station
Ground Station	n/a

FOR MORE INFORMATION	
Manufacturer	Teledyne Ryan, Inc.
Website	n/a

Gnat 750

PHYSICAL CHARACTERISTICS	
Height	n/a
Weight	1,142 lbs.
Length	17.4 ft.
Diameter	n/a
Wingspan	35.3 ft.

PERFORMANCE CHARACTERISTICS	
Altitude	25,000 ft.
Range	3,022 nm
Endurance	48 hrs.
Cruise Speed	53 mph
Maximum Speed	161 mph
Propulsion	120 hp

PAYLOAD SPECIFICATION	
Electrical	3 kw
Weight	140 lbs.
Height	n/a
Width	n/a
Length	n/a
Temperature	n/a

COST INFORMATION	
Vehicle	$1.2-1.8M
Ground Station	$5-6M

FOR MORE INFORMATION	
Manufacturer	General Atomics
Website	n/a

Pioneer

PHYSICAL CHARACTERISTICS	
Height	n/a
Weight	452 lbs.
Length	13.98 ft.
Diameter	n/a
Wingspan	16.76 ft.

PERFORMANCE CHARACTERISTICS	
Altitude	12,000 ft.
Range	115 nm
Endurance	5.5 hrs.
Cruise Speed	65 kts.
Maximum Speed	110 kts.
Propulsion	26 hp, gasoline

PAYLOAD SPECIFICATION	
Electrical	500 wts.
Weight	75 lbs.
Height	approx. 15 in.
Width	approx. 15 in.
Length	approx. 15 in.
Temperature	ambient

COST INFORMATION	
Vehicle	$900K
Ground Station	n/a

FOR MORE INFORMATION	
Manufacturer	Pioneer UAV, Inc.
Website	http://www.puav.com/intro.asp

Shadow 200

PHYSICAL CHARACTERISTICS	
Height	n/a
Weight	215 lbs.
Length	9 ft.
Diameter	n/a
Wingspan	12.75 ft.

PERFORMANCE CHARACTERISTICS	
Altitude	15,000 ft.
Range	32 nm
Endurance	4 hrs.
Cruise Speed	84 kts.
Maximum Speed	150 kts.
Propulsion	37 hp

PAYLOAD SPECIFICATION	
Electrical	500 wts.
Weight	50 lbs.
Height	approx. 12 in.
Width	approx. 12 in.
Length	approx. 12 in.
Temperature	ambient

COST INFORMATION	
Vehicle	n/a
Ground Station	n/a

FOR MORE INFORMATION	
Manufacturer	AAI Corp.
Website	n/a

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14. ABSTRACT

Monitoring threatened and endangered species on Army installations is not always feasible with respect to the areas that are either inaccessible or have limited times for entry. When biologists are unable to enter an area freely for periodic surveys, it prevents normal application of standard methods, which results in the data being unavailable for reporting either management successes or problems. If these species are present in the inaccessible area, they cannot be credited toward management goals. The total population of the installation is assumed to be smaller, which can result in unnecessary expense and greater regulatory interference. This research examines each of the four broad categories of platforms (1) remote sensing, (2) airfoil aircraft, (3) lighter-than-air craft, and (4) ground surveillance instrumentation for remote or non-intrusive acquisition of data relevant to these species. The data might be of any nature, including spatial relevance, sound, presence or absence, or other categories. Some technologies, such as satellite and aerial imagery, continue to fill important niches, which are generally well understood. The overall conclusion of this survey was that there are no fully satisfactory, affordable platforms that can provide the full set of data acquisition needs for inaccessible areas.

15. SUBJECT TERMS
Threatened and Endangered Species (TES), ecological surveys, remote sensing, range management, surveillance

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